BNFL
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Section 3.6

Sample Carrier Breakout

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Sample Carrier Breakout

3.6.1   Work Identification

This report demonstrates an application of the integrated safety management process to an example of sample carrier breakout. This report focuses on the hazards associated with the breakout of a sample carrier from the pneumatic sample transfer system connecting the process facility to the laboratory.

This example considers the breakout of a carrier containing a sample taken from the High Level Waste (HLW) Receipt tank.

The process requires waste feed to be sampled and analyzed to qualify the feed for treatment, to support specification and control of process parameters, and to demonstrate that limits are not exceeded in the immobilized waste product. An automatic sampling system obtains feed samples from the process stream, locates them in sample bottles, and loads the bottles into sample carriers. The sample carriers are transported to the laboratory through piping, by a vacuum driven pneumatic system. Schematics of the automatic sampling equipment are provided in Figure 3.6-1, Figure 3.6-2 and Figure 3.6-3.

The pneumatic sample transfer system was not specifically addressed in the *Initial Safety Analysis Report* (BNFL Inc 1998c) or in the *Hazards Analysis Report* (BNFL Inc 1998a). During execution of Part A of the Tank Waste Remediation System – Privatization (TWRS-P) contract (DOE-RL 1998), the system was described in the sampling philosophy document (Richards, Hughes and Richardson 1997).

3.6.1.1   Key Process and Design Parameters

3.6.1.1.1   Process Description

The need to sample the waste feed has been described in Section 3.6.1 and the functions of the sample carrier are described in the following section.

Samples are taken from process vessels by automated sampling equipment, or autosamplers, which obtain samples and transfer them to the laboratory via a pneumatic system. The autosamplers will be shielded as personnel protection requirements dictate. Samples will be taken according to an approved sample schedule, which will identify the frequency of sampling and the types of analyses to be performed.

The pneumatic approach to sample transport reduces the total exposure of operators to sample radioactivity by reducing the duration of exposure. Manual intervention is minimized. The pneumatic piping will be located to maximize the distance between the piping and the operating personnel, and to avoid high-occupancy areas (the layout of piping is not yet complete). **Open Issue**.

Much of the following process description is from *Hanford TWRS Plant Sampling Philosophy* (Richards, Hughes, and Richardson 1997), which was prepared in support of Part A of the TWRS-P contract. Some design conditions and parameters have changed since the Part A documents were prepared. In particular, the source term estimate used in the sampling philosophy document is no longer current. Additional work

has been performed to update the source term to reflect receipt of combined envelopes B and D feed in the high level waste receipt tank, rather than envelope D feed alone. The sampling philosophy document indicated that the separated cesium stream was the highest activity stream. Although it represents the worst case for shielding, the cesium stream has not been used for dose calculations in this report because it does not create the worst-case dose in the event containment is lost.

The combined envelope B and envelope D feed has been evaluated in this example because it is expected to be among the worst case samples from a dose standpoint. Preliminary evaluation of the other streams to be sampled and transported by the pneumatic system on a less frequent basis shows that all have dose consequences similar to or below the HLW receipt tank sample. The transuranic isotopes of americium cause most of the dose consequence after inhalation.

The contract maximum for envelope B (Contract DE-AC06-96RL13308-Mod A006 Specification 7) has been used to establish the material at risk for the supernatant transferred with envelope D solids. The envelope B activity has been adjusted to be based on the maximum sodium concentration of 10 molar. (Elsden, 1999) The liquid portion of the HLW feed is,

Radionuclide	Concentration (Curies/liter)	Basis
TRU	0.0001	Envelope B at 10 molar sodium
Cs 137	5.4	Envelope B at 10 molar sodium
Sr 90	0.012	Envelope B at 10 molar sodium
Tc 99	0.0019	Envelope B at 10 molar sodium
Co 60	0.000016	Envelope B at 10 molar sodium
Eu 154 + 155	0.0003	Envelope B at 10 molar sodium

For the solids component (envelope D) the inventory for tank 241-AZ-101 is based on the Best Basis inventory. This inventory has been averaged over the retrieved solids mass in the tank because of the mixing that USDOE must perform to retrieve and transfer the material to the facility. A feed concentration of solids at 200 grams per liter has been selected as this represents the maximum unwashed solids concentration in the contract specification for envelope D solids. Tank 241-AZ-101 was selected as the basis for the source of radionuclides because it contains the highest concentration of radionuclides of concern among the three candidate HLW feed tanks. The material at risk for selected radionuclides in the HLW Feed Solids (Elsden 1999) is shown below:

Radionuclide	Concentration (Curies/liter)	Basis
Sr 90	8.1	Tank 241-AZ-101 conc at 200 grams per liter solids
Pu 239	0.0016	Tank 241-AZ-101 conc at 200 grams per liter solids
Am 241	0.038	Tank 241-AZ-101 conc at 200 grams per liter solids
Cm 243 + 244	0.0001	Tank 241-AZ-101 conc at 200 grams per liter solids

Following is a general description of how the automatic sampling system will operate:

- The pneumatic piping system can be operated to send a sample carrier in either direction in the pneumatic pipe. This allows fresh sample bottles to be delivered to the automatic sampler, and samples to be returned to the laboratory. The piping system incorporates diverters to allow transport to different destinations. In the carrier receipt and bottle/carrier transfer facility, clean sample bottles equipped with stoppers and weirs are installed in sample carriers by automated equipment. The carriers are then introduced into the pneumatic system for transport to the selected sampler.

- The carrier/bottle assembly is transported to the sampling station's controlled arrival facility, which provides for soft docking of the unit. The arrival of a carrier is detected at the sampler by a proximity switch. The HLW receipt tank sampler obtains a sample using a reverse flow diverter (RFD) dedicated to sampling. All samples fed to autosamplers are filled via RFDs. This sampling method is used extensively at other BNFL facilities. The automatic sampler is a sealed containment equipped with six sampling needles and a robotic arm. The arm removes the carrier lid, which retains the sample bottle. The arm then transfers the bottle to one of the sampling needles where it is impaled, upside down, on the tip of the needle, which passes through the bottle's self-sealing stopper. The stoppers are firmly fixed to the sample bottles by means of an interior seal and a rolled, exterior seal, as shown in the following figure.

AIR DRAWN OUT
OF BOTTLE TO
EVACUATE
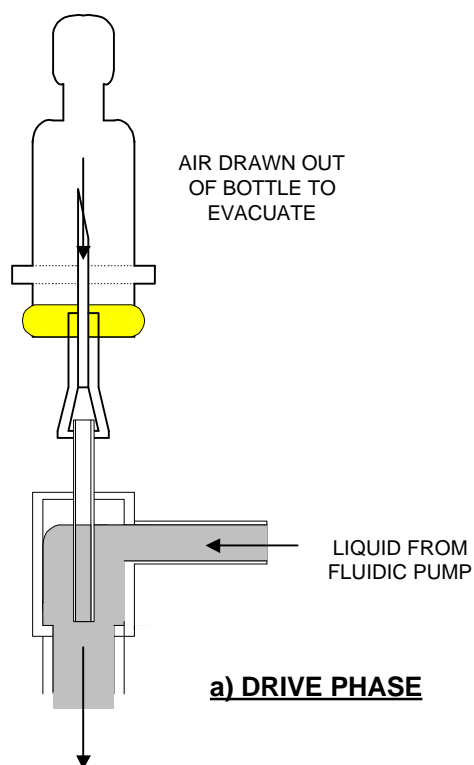
When the pump is delivering liquid along the delivery line, the liquid will have some velocity. As the liquid passes the end of the sampling needle, there is a venturi effect, which draws air down the needle from a sample bottle on the other end of the needle.

LIQUID FROM
FLUIDIC PUMP

a) DRIVE PHASE

SAMPLE DRAWN INTO
BOTTLE DUE TO
VACUUM
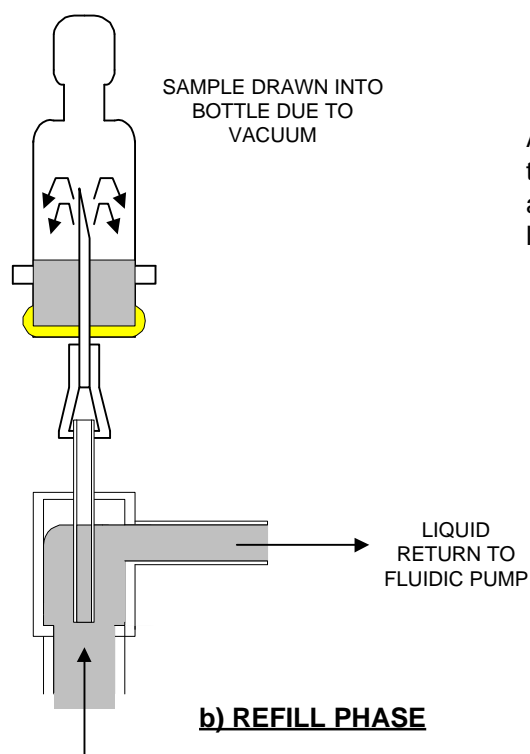
As the delivery pulse from the pump ends, the liquid velocity past the needle decreases and the partial vacuum in the bottle draws liquid back into the bottle

LIQUID
RETURN TO
FLUIDIC PUMP

b) REFILL PHASE

A weir in the bottle prevents loss of sample during subsequent pulses. To a limited extent, additional pulses will increase the sample volume. A sample bottle cannot be overfilled, since the flow of sample depends on creation of a partial vacuum in the void space of the sample bottle. If, by error, a sample bottle is dispatched to an autosampler without a stopper, no sample can be taken because no vacuum can be pulled on the bottle.

The automatic sampler removes the bottle/carrier lid assembly from the needle, inserts the bottle into the carrier and fastens the lid. The carrier lid is sealed by the autosampler prior to transfer. The carrier is then transferred pneumatically to the shielded laboratory receipt facility.

A sketch of the sample bottle carrier is provided below:

pneumatic transfer seal
(felt)

pneumatic transfer seal
(felt)

carrier lid
(stainless)

carrier body
(polyethylene)
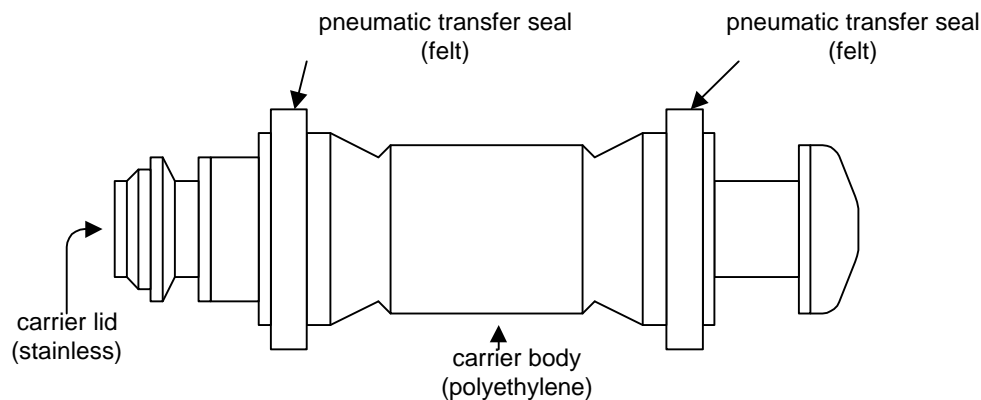
3.6.1.1.2 Design Parameters

Specific design parameters of the automatic sampling system are provided below. The details given are focused on information that is relevant to the carrier breakout accident.

Volume. The volume of the sample bottles used to transport HLW samples is assumed to be **25 mL**. This assumption is based on use of the standard BNFL sample bottle, which is 1 inch diameter at the top (Richards, Hughes, and Richardson 1997). The sample bottle is about 4.3 inches long. Approximately **30 samples per day** will be transferred to the laboratory for analysis (Richards and others 1997). Of these samples, approximately **one 25-mL sample per day** will be taken from the HLW receipt tank (Richards and others 1997). **Design Assumptions**

Source Term. The source term for this example is based on the combined feed envelopes B and D located in the HLW receipt tank. The source term used in consequence calculations (Smith 1999) has a unit liter dose, on inhalation, of 2.0×10^7 rem/L (Kummerer 1999). The consequence calculations (Smith

1999) take into consideration event geometry and are based on isotopes of radiological significance (Kummerer 1999).

Speed. The speed of the sample carrier is assumed to be approximately 20 ft/s (Richards et al. 1997), which is the same velocity as is used in the Thermal Oxide Reprocessing Plant (THORP) plant at BFNL's Sellafield site. **Design Assumption** Although the carrier passes though occupied areas of the plant, the speed of the carrier and the distance to the piping minimize the dose to operators and co-located workers. The section of transport pipe near the point of sample departure is designed to allow an inrush of air to accelerate the carrier to its travel velocity. The sections of transport pipe where acceleration and deceleration occur may also be shielded.

Transfer Pipe. The pneumatic transfer piping is constructed of unplasticized polyvinylchloride (uPVC). The *BNFL Pipeline Specification* (BNFL 1995) calls for commercially available PVC pipe with specific dimensions, including inside diameter of 75 mm, 90° bends of 500-mm radius, and parallel sleeve fittings with no central stop. The *BNFL Pipeline Specification* has been used to procure pneumatic piping for existing BNFL systems, and it is called out by Section 4.2 of the TWRS-P Safety Requirements Document (BNFL INC. 1998d). It provides a low cost, resilient system capable of withstanding a wide range of environmental conditions. BNFL evaluated alternative materials for the piping system, including mild steel, stainless steel, and aluminum, and concluded that uPVC was the best choice based on functional suitability, ease of fabrication, and cost (Sperinck 1985).

Sample Bottles. Sample bottles are constructed of robust high density polyethylene (HDPE) incorporating a rubber cap that self-seals after extraction of the sample.

Sample Carriers. The sample carriers are sealed containers used to carry sample bottles within the pneumatic transfer system. They are constructed of a high density polyethylene body, a stainless steel end cap attached to the plastic body, a stainless steel top insert into the open end of the plastic body and a stainless steel lid and lock mechanism. The cavity within a carrier is cylindrical. At the opposite end to the carrier lid there is a magnet that operates the reed switches along the length of the transfer tubes. The carriers are about 2.5 inch in diameter (body) and 7.8 inch long. At each end, around the circumference of the carrier, are bands of felt on which the carrier slides through the transfer piping. The felt also provides a pneumatic seal. The felt will be periodically measured and replaced when wear is excessive.

The carrier lid has a recessed spring-loaded plunger mechanism which, when operated, allows latches to withdraw into the lid mechanism and thereby release the lid. A similar mechanism holds the sample bottle in the inside of the lid. This type of lid has been proven by BNFL experience to prevent the lids detaching and/or leaving a sample bottle behind in the transfer pipe or automatic sampler. A seal is generated between a lip on the lid and the carrier body top by virtue of their close fit, accurate construction, and a sealing ring. The sample carrier provides complete secondary containment for the sample bottle. The carrier travels magnet-end first when carrying a sample.

Travel path. The pneumatic transfer piping goes through a number of contamination control barriers, beginning in the automatic sampler, which is C5, proceeding though C3 and C2 areas (with lower levels of contamination), which may be occupied, and ending in a laboratory receipt cell, which is also a C5 area. The piping will be designed where practicable to maximize distance from operators and avoid areas of frequent occupation. **Design Assumption** The air being pulled through the interior of the pneumatic pipe is exhausted through HEPA filters. **Design Assumption** The fan is not capable of collapsing the transfer piping even if applying its maximum vacuum (**Safety Function**). Maintaining containment within the sample bottle and sample carrier controls contamination from the samples.

Monitoring. Empty carriers are monitored at the Laboratory Receipt Facility. If contaminated, they are routed to the Contaminated Carrier Receipt Facility. Each carrier journey (also called a "flight") is timed using a series of switches distributed along the outside of the pneumatic piping. The switches track the carrier throughout its journey. Should the journey time exceed prescribed limits, an indication is provided that maintenance may be required on the transfer line or sample carrier. The prescribed time limits are set up to differentiate between late and non-arrival, therefore indicating whether a carrier was merely slow, in contrast to one which might be stuck or ejected. When carriers are slow, the felt seals are measured and the line integrity checked to be satisfactory. Carriers are designed to make the seal replacement task a very simple operation (Richards and others 1997). Routinely-occupied areas are equipped with area radiation monitors, which would alarm in the event that a carrier with high enough activity were stationary in the vicinity. **Design Assumption** The area radiation monitors incorporate timers so that the usual rapid passage of a sample though the area would not activate the alarm. The system is controlled to ensure only one sample carrier is transferred at any time.

3.6.1.2 Interfaces

Interfaces that are relevant to analysis of the carrier breakout event are as follows:

HLW Receipt Vessel. This is the tank inside the TWRS-P facility that will receive combined envelope B and D wastes from the DOE.

TWRS-P Laboratory. The TWRS-P Laboratory will be equipped to receive and analyze samples, introduce new sample bottles and carriers into the system, maintain sample carriers, and remove any highly contaminated carriers. Sample receipt occurs in the Laboratory Receipt Facility, which is a C5 area. The Carrier Receipt and Bottle/Carrier Transfer Facility is used to load in sample bottles, install them into carriers, and to dispatch carrier/bottle assemblies. The Contaminated Carrier Receipt Facility will be used for safe removal of contaminated carriers (Richards and others 1997). All HLW receipt tank sample transfers will be within the pretreatment building. This is true for all liquid samples.

Automatic Sampling Units. The automatic samplers are installed in several locations around the plant, including the HLW receipt vessel. The automatic sampler containment is always vented, via the drain line to the C5 ventilation system. A process water spray head is designed into each automatic sampler to remove any build-up of activity around the sample needles which may occur. Automatic Sampling units are typically operated by programmable logic controllers (PLCs). They are a part of the plant control and instrumentation systems (Richards and others 1997). A proximity switch at the automatic sampler detects the arrival of a sample carrier.

Air Service (Pneumatic). The sample transfer system is operated pneumatically. A vacuum system pulls air through the transfer piping, and exhausts through HEPA filtration.

Multiple User System. The pneumatic sample system is a branched network of piping. The branched lines are furnished with diverters, which are used to direct the sample carrier to the correct destination. The sample transfer system will handle approximately 30 samples per day, from various vessels. More than one carrier may use the same route, but only one flight at a time takes place. The system may handle as many as 10,000 samples per year (Richards and others 1997). Sample paths are pre-selected by the programmable logic controllers (PLCs).

3.6.1.3 Setting

The automatic sampling and transfer system traverses a number of areas of the plant. In particular, the sampling setting includes the following areas:

Location	Area Classification Zone
Vessel being sampled	Vents into C5
Automatic Sampling Unit Chamber	C5
Pipe Run	C2
Laboratory Analytical Areas	C3
Laboratory Hot Cell	C5

The pneumatic transfer pipes will be located near the room ceilings. In occupied areas this is assumed to be a maximum of 25 feet (8 meters) above the floor. **Design Assumption**

The pneumatic sample transfer system will operate at ambient plant temperature.

The carrier breakout event is assumed to occur within the process building, in a C2 area, since these areas are normally occupied, resulting in exposure to operators.

The pneumatic piping is assumed to be installed in compatible environments, at a maximum distance from operators, and avoiding areas of frequent occupation wherever practical. This will require procedural instructions to control the layout **Design Assumption**.

3.6.1.4 Operating Environment

The automatic sampling system is exposed to an operating environment that includes the chemical and isotopic composition of solutions being sampled and the maximum temperature of vessel contents. The potential exists for the automatic sampling system to become contaminated under fault conditions. The transfer pipe will be exposed to ambient building atmosphere.

3.6.1.5 Applicable Experience

Sellafield. An automatic sampling and pneumatic transfer system has been widely used and is a proven technology used by BNFL at Sellafield. Extensive testing was conducted using a cross-site test loop to demonstrate the pneumatic transfer system reliability and durability, and the system has seen significant active use. Experience with existing systems was used in preparing the TWRS-P Sampling Plan and conceptual design presented in Part A, which forms the basis of this evaluation.

Actual experience includes:

- Prior to completion of active Autosampling System commissioning, THORP plant operations had taken over 30,000 active samples, which represents approximately 180,000 flights. (Transport of each sample from the sample point to the analytical laboratory at THORP involves 6 flights. Three of the flights involve samples. Samples are not present for the remaining three flights.) During this time there was a single event of breakout from the pneumatic pipe. This event was related to a failed

joint in a bend and resulted in two carriers dropping out of the pipe. The presence of two carriers in the pipe was due to an unrelated control system failure.

- A number of improvements to the THORP system were implemented as a result of the pre-commissioning experience. These improvements include improved piping supports, increased carrier maintenance (replacement of felt seals), improved carrier latching mechanisms, improved procedures, and improved sample needles and bottles.

- Active commissioning of the THORP Autosampling System was concluded in December of 1996. Since then, approximately 21,000 active samples per year have been taken within the THORP facility. A repeat of the event described above has not occurred. For 1997 and 1998 there were a total of 42,000 samples and 252,000 flights. During this time, there was a single event of a breakout from the pneumatic tube. This breakout did not involve sample material, or any weakness in the pneumatic pipe, but rather use of an incorrect procedure to recover carrier internals from the pipe (Longfellow, 1999).

- Using the data from both phases of THORP operations, there have been 2 breakout events during the handling of about 72,000 samples (over 400,000 flights).

- Total length of pneumatic piping (inside of the building within the THORP facility) at Sellafield is about 11,500 feet (3,500 m). The length of piping within TWRS will be approximately 2,500 feet (760 m).

- No releases of sample material have occurred due to carrier breakout.

3.6.2   Hazard Evaluation

3.6.2.1   Hazard Identification

For this example, the hazard arises when a sample carrier breaks out from a transfer line of the Pneumatic Transfer System. The most onerous radiological consequences would arise if the breakthrough occurred in the section of the Pneumatic Transfer System routed through the routinely occupied C2 areas of the facility and if containment of the sample in the sample bottle and carrier were lost. Breakthrough of a carrier would expose the operator to a direct radiation dose. Loss of containment would then expose the operator to an additional inhalation dose. The dose in this event is dominated by the inhalation pathway. The event has lesser consequences for the co-located worker and the public than for the facility operator.

The initiating event is breakout of a sample carrier from the pneumatic transfer pipe.

3.6.2.2   Event Sequence

For a loss of containment to occur, the event sequence would be as follows:

- The sample carrier breaks through the pneumatic pipe

- The carrier is either:

    1.   improperly closed due to an unrelated event

2. physically damaged by impact with a solid obstruction (e.g. structural wall) upon ejection from the pneumatic transfer system with sufficient energy to compromise the integrity of the sample carrier.

- The sample bottle is either:

  1. already leaking inside the carrier due to an unrelated event
  2. ejected from the damaged carrier and loses containment due to the impact.

- A release of airborne activity could therefore occur at the moment of impact and be followed by the release of sample liquor from the sample bottle and carrier. The facility worker is therefore potentially exposed to both an inhalation dose from the airborne activity release and an external radiation dose from the spilled sample. The spilled sample would also continue to present an inhalation hazard to the operator by the resuspension of activity in the airflow across the liquor surface, until the spillage is adequately recovered. Airborne activity generated from the impact and resuspension could ultimately be released to the environment resulting in a public dose detriment.

Other hazards associated with the pneumatic transfer system have been identified that are not part of this event sequence. These include a stuck sample carrier within the transfer lines. Such hazards will need to be addressed separately in subsequent hazard evaluations. **Open Issue**

For the purposes of this example the event sequence is defined as consequences arising from a carrier breakthrough from the transfer pipe.

3.6.2.3   Unmitigated Consequences

Details of the consequence calculation are presented in a calculation (Smith 1999).

The unmitigated consequence calculations described below take no credit for sample bottle or carrier containment. The consequence model is conservatively based on spilling 100% of the entire 25-mL HLW sample. Experience from operating facilities in the U.K. indicates that sample volumes larger than 15 mL are rare, and that realistic volumes achieved by autosampling are in the range of 5 to 10 mL (Richardson 1997). The consequence calculation is conservative due to use of the maximum sample volume.

Assumptions made were:

The carrier breakout occurs in an occupied area of the Pretreatment Building, which includes the HLW receipt tanks and the laboratory that processes those samples. Occupied areas are assumed to have a floor to ceiling height of 25 feet (8 m) or less, according to the currently planned layout (SK-W375 PT-PL-00007, Rev. A, "TWRS–P Building Layout Pretreatment Facility Section A and B." Other areas in the pretreatment facility have higher ceilings, but they are not occupied.

The entire sample is assumed to be released at the breakout elevation, and then to free-fall to the floor.

The sample is pessimistically assumed to land in close proximity to the facility worker.

The sample is assumed to have the source term given in Section 3.6.1.1 and a dynamic viscosity of 3 centipoise, which is the minimum described for this waste type in the Waste Feed Delivery Technical Basis (Orme 1998).

If the breakthrough from the transfer line is pessimistically assumed to occur at the maximum height of 25 feet (8 m), then the airborne release fraction (ARF) for the initial release upon impact is 1.0×10^{-4} (Smith 1999). The airborne activity released is assumed to be 100% within the respirable range. The volume released is then $(1.0 \times 10^{-4}) \times 25 \text{ mL} = 2.5 \times 10^{-6}$ L.

The airborne release is initially assumed to be uniformly distributed in a rectangular volume of 282 ft^3 (8 m^3) which comprises a cubic breathing zone surrounding an approximately 6-ft (2-m) tall operator. This volume is consistent with the assumption that the sample strikes the floor in close proximity to the worker; it is the value for volume used for the 20 seconds of exposure. For the event that the worker is unaware of the hazard and potentially remains in the immediate area for up to 8 hours, credit is taken for dispersion of the airborne activity. A nominal control volume of 10,600 ft^3 (300 m^3) is therefore assumed (for the balance of the 8 hours), which represents an area of 33-ft x 33-ft x 10-ft high into which the activity would disperse.

The direct radiation dose was calculated by assuming the operator to be 3.3 ft (1 m) from the source. This is bounding for whole-body dose from a ground level source to an operator approximately 6-ft (2-m) tall.

The following text and table summarize the results of the consequence calculation:

Facility Worker

The inhalation dose for the initial release through the eight-hour exposure would be 0.74 rem.

The airborne release fraction due to resuspension of the spilt liquor is 4×10^{-7}/h (Smith 1999). This is insignificant compared to the release from free fall, which has an airborne release fraction of 1.0×10^{-4}/h. The dose over eight hours from resuspension would be $(8 \text{ h} \times 4 \times 10^{-7}/\text{h}) \times 0.74 \text{ rem}/(1.0 \times 10^{-4}) = 0.02$ rem

For an eight-hour exposure at a distance of 3.3 ft (1 m) the direct radiation dose would be (at most) 0.08 rem (Woodruffe 1999). (The estimate in (Woodruffe 1999) is based on a higher estimated source term for HLW than is currently expected for this sample. Additional calculations were not performed to correct for the reduction in source term because the contribution of direct radiation is only a small part of the total dose. Reducing the source term would not affect the overall results.)

The total dose to the facility worker would be $0.74 + 0.02 + 0.08 = 0.84$ rem.

Co-located Worker

The inhalation dose would be 2.0×10^{-4} rem.
The direct radiation dose for a sixteen-hour exposure at 328 feet (100-m) distance is considered to be negligible.

Public

Inhalation dose = 2.9×10^{-7} rem
The radiation dose to the public is considered to be negligible.

Unmitigated Dose Consequences [a]

Receptor	Dose (rem)	Severity Level
Facility Worker	0.84	SL-4 (assumed SL-3)
Co-located Worker	2.0×10^{-4}	SL-4
Public	2.9×10^{-7}	SL-4

[a] All pathways dose

- **Severity Level**

Based on the evaluations above, the Severity Level of this event is SL-4. Due to the proximity of the calculated dose to the SL-3 threshold, a severity level of SL-3 is adopted. The target frequency for SL-3 designated events is 10^{-2} per year.

- **Chemical Hazards**

The chemical hazards associated with the sample breakout event include exposure to a caustic solution. The radioactive nature of the sample assures that appropriate steps will be taken to protect personnel from exposure and to decontaminate personnel in the event of contact. The small quantity of the sample (25 mL maximum) makes the chemical risk to the public from a carrier breakout negligible.

- **Conventional Safety Hazards**

The potential exists for a significant personal injury as a result of an ejected sample carrier striking a facility worker. Subsequent loss of sample containment is not relevant to this hazard. To minimize the radiation exposure of the facility workers the transfer line routing will aim to avoid routinely occupied areas whenever practicable, this will also reduce the probability of injury in such an event. The conventional safety aspects of this event will need to be addressed in detail as the design develops. **Open Issue.**

3.6.2.4 Frequency of the Initiating Event

In order to define a frequency estimate for the sample carrier breakthrough event, actual operating experience from BNFL's UK Sellafield operations has been employed.

Based on THORP Pneumatic Transfer System experience (Longfellow 1999), the probability of a carrier escaping from the pneumatic pipe is 2 per 432,000 flights. This is 2 events per 72,000 samples (2.8×10^{-5} per sample), however each sample involves 6 carrier flights, of which the sample is only present for 3.

Approximately 30 samples per day are expected to be taken in the TWRS-P facility. Of these 1 per day (365/y) is HLW. The actual number of HLW samples will likely be lower, given the length of time it will take to process the contents of an entire tank. The timing of HLW samples is not completely established at this point in the design, therefore the HLW receipt tank sample rate is assumed to be once per day.

As a result, the initiating event, which is that the sample carrier breaks out of the pneumatic pipe with a HLW sample in it, has a frequency of:

f = (2 breakouts/72,000 samples) x (365 HLW samples/y) x (0.5 probability that carrier contains a sample)

f = 5.1 x 10^{-3} HLW sample breakouts per year.

The frequency above is only for the breakout of a sample carrier with a HLW sample in it. After the breakout occurs, the sample may or may not lose containment.

3.6.2.5 Natural Phenomena Hazards and Man Made External Events

3.6.2.5.1 Natural Phenomena

Natural phenomena hazards (NPH) and their treatment on a plant wide basis are included in Section 2.10. The safety functionality identified there is assumed to be provided. **Design Assumptions**. With the exception of a seismic event, these phenomena do not have significant potential to influence HLW sample carrier breakthrough because the transfer lines are within the building and the building structure provides protection. In addition, the design is not particularly sensitive to the temperature variations outside the building because of the operation of the ventilation systems and the thermal inertia of the system.

Seismic events are a clear potential initiator for damage to the transfer pipework. However, a seismic event would have to be sufficiently strong and be concurrent with a sample transfer to initiate this event. The most likely scenario is that the failed piping would prevent a vacuum being maintained and the carrier would stop in the pipe.

3.6.2.5.2 Man Made External Hazards

Similarly, man-made hazards and their treatment on a plant-wide basis are also discussed in Section 2.10. There are no such hazards that uniquely affect this event.

3.6.2.5.3 Common Cause Events

A fire could damage the pneumatic piping, the sample carrier, and the sample bottle. A fire would also prompt immediate evacuation and additional protective measures for re-entry. This topic will be considered further under the integrated safety management process as detail design develops, but is not expected to add significantly to risk. **Open Issue**.

3.6.3 Control Strategy Development

The Severity Level of SL-3 for this event requires the event frequency to be $<10^{-2}$ per year. The initiating frequency of 5.1 x 10^{-3} per year achieves this which indicates no further control strategy development is required to manage the hazard. This frequency has been derived from data taken from BNFL UK experience of a similar system which integrates well-developed and proven control strategies. This section describes the potential control strategies that have been identified and reviewed to demonstrate, for the purposes of this example, the robust nature of the mature control strategies in the TWRS design.

3.6.3.1   Controls Considered

The first step in this process was to identify candidate controls. The following controls were considered to prevent a sample carrier breakout (or mitigate its consequences):

- Improve Pipe Material. Higher integrity piping (e.g., stainless steel) could reduce the potential for breakout.

- Strengthen Pipe in Key Areas. Pipe bends and joints are the areas most vulnerable to breakout. Strengthening the piping at these areas could reduce the potential for carrier breakout.

- Increase the Radius of Pipe Bends. Installing larger radius bends might reduce the degree of wear caused by passage of the sample carrier.

- High Integrity Secondary Containment (Sample Carrier). The sample carrier provides secondary containment of the sample. A high integrity sample carrier would withstand the induced forces of a breakout

- Sample Transfer Tracking. Prompt alerts of the failure of a sample transfer to be completed would reduce the amount of time operators could be exposed, thus reducing potential doses. This would act to mitigate the consequences of the event.

- Pipe Run Instrumentation. Instrumentation on the pipe run (e.g. pressure) would provide an early warning of certain types of pipe failure. This would both reduce the likelihood of sample carriers being 'flown' down damaged lines and reduce the amount of time operators could be exposed to a sample carrier or its contents.

- Optimize Pipe Layout. The pipe layout will be optimized to reduce the number of bends. This would reduce the number of locations at which a breakout could occur. This action is assumed to be good engineering practice, and has been described earlier.

- Reduce Sample Sizes. The sample volume could be reduced, thus reducing the potential dose to operators.

- Install Catch Nets. Catch nets installed along the piping system would prevent the carrier from falling to the floor. This would not prevent the breakout but would reduce the likelihood of sample release.

- Route Pipe through C3 Contamination Areas. C3 Contamination Areas are posted for surface contamination and require operators to observe more stringent requirements (such as wearing respirators) than in C2 contamination areas. If the piping were routed only through C3 areas, personnel are more likely to be equipped with additional protection, thus reducing the dose in the event of sample carrier breakout.

- Route Pipe to Avoid Areas of Occupation. If the pipe avoids areas of occupation, the probability of a sample carrier breakout near personnel would be reduced.

- Area Radiation/Continuous Air Monitoring. Monitoring in occupied areas would detect the presence of a sample carrier if it stopped in the piping or if it was ejected into the room and lost containment.

- Fully Automatic Plant. A fully automatic plant would not require operators to be present, thus reducing potential exposure in a sample carrier breakout event.

- Use of Coaxial Pipe. Use of a pipe-in-pipe system for the pneumatic transport would provide containment in the event of sample carrier breakout in the inner pipe.

- Routine Carrier Maintenance. Operating experience has shown that scoring of the inside bends of the pneumatic pipe can occur when the sample carrier external felt seals become worn. Regular replacement of the felt seals would reduce the likelihood of carrier breakout by preventing pipe wear. This type of regular maintenance was successfully instituted at THORP in response to reduced carrier travel performance.

- High Reliability Carrier Lid. Use of a high reliability carrier lid would prevent loss of the sample in a breakout event by ensuring that lids are properly installed at the sample station. This improvement has been implemented at THORP. (This assumes that the balance of the carrier also has a high integrity).

- Condition Monitoring. Monitoring the condition of the carrier (e.g. for proper lid installation) prior to its flight would ensure that containment has been provided, thus reducing the likelihood of loss of sample due to a breakout.

- Improved Sample Bottle Integrity. Sample bottles might be improved to reduce the likelihood of sample loss in a carrier breakout event. The sample bottles in use at THORP are the result of a number of years of continued improvements aimed at improving containment integrity and are considered extremely robust.

- Reduce Sample Bottle Sampling Failures. The sampling system could be improved to reduce the number of times a needle could break off in the stopper (A broken needle in the stopper could result in the loss of a droplet or two of the sample). The result of this would be to reduce the potential for the inside of the carrier to be contaminated at the outset of a breakout event. (This action has already been taken at Sellafield, where the needle assembly has been replaced by a one-piece metal unit).

- Reduce Speed of the Sample Carrier. The speed of the sample carrier could be reduced in order to reduce the amount of energy that could be imparted to scoring the inside of the pneumatic pipe. This could reduce the frequency of sample carrier breakouts.

3.6.3.2   Control Strategy Selection

Control strategy selection was based on a two-step process; first, clearly unrealistic control elements were deleted; second, engineering tradeoffs were considered to further down—select the options, and a preferred control strategy was selected.

3.6.3.2.1 Step 1 (Initial Screen)

The merits of each of the potential controls described above were considered primarily against the following set of criteria:

- Effectiveness

- Practicability

- Reliability

- Demonstrability

- Compliance with laws and regulations

- Ability to comply with DOE/RL-96-0006, *General Radiological and Nuclear Safety Principles* (in particular, use of proven engineering practice, ease of providing inherent/passive safety features, radiation protection features, and avoidance of undue reliance on human actions).

The objective of this review was to identify the main advantages and disadvantages of each control, and also to eliminate those which were not considered viable against the criteria above in formulating a composite control strategy. The results of the process are shown in Table 3.6-1.

Table 3.6-1. Initial Evaluation.

Control	Advantages	Disadvantages	Compliance with Top Level Principles	Further Consideration in Control Strategy
Improve Piping Material to Reduce Potential for Breakout	Improves system integrity against breakout of carrier Pipe is less susceptible to external damage	May introduce operational problems, e.g., recovery of a stuck sample carrier could increase doses Cost	Yes	Yes
Strengthen Pipe in Key Areas	Places protection at point of vulnerability	May require monitoring to demonstrate continued performance Cost	Yes	Yes
Increase the Radius of Pipe Bends	Reduces wear on bends caused by passage of the sample carrier.	The improvement afforded by this change cannot be accurately quantified System routing may be constrained by building layout	Yes	Yes (Good engineering practice)
High Integrity Secondary Containment (sample carrier)	Ensures confinement of the material in the carrier in the event of a carrier breakthrough	Demonstration of integrity may be required	Yes	Yes
Sample Transfer Tracking System	Provides information about successful transfers of samples Indicates last position carrier passed	Does not prevent the event Does not provide notification to workers in the vicinity of the failure	Yes – proven practice	Yes (Considered for defense in depth, but not as a primary control strategy)
Pipe Run Instrumentation (e.g., pressure)	Gives immediate indication of system failure	Only prevents event if carrier transfer can be stopped	Yes - proven practice	Yes
Optimize Pipe Layout (reduce number of bends)	Reduces the possibility of breakout	Impractical to eliminate all bends	Yes	Yes

Table 3.6-1. Initial Evaluation.

Control	Advantages	Disadvantages	Compliance with Top Level Principles	Further Consideration in Control Strategy
Reduce Sample Sizes	Reduces consequence from a single event	Requires more samples causing greater burden on sampling system and laboratory	No – increased use of active system; increased potential for radiation exposure	No
Install Catch Nets at Bends	Prevents drop of carrier to floor Reduces probability of loss of containment due to impact	Does not prevent the hazard of carrier breakthrough Not effective if carrier/bottle fail independently, releasing liquid to the floor (this is the reference case). Recovery of the carrier from a net may increase the dose to personnel	No – requires human recovery actions; potential for increased radiation exposure	No
Route Pipe through C3 Areas	Protects workers who would have been in C2 areas from potential contamination due to increased protective requirements, such as respirators	Does not prevent breakout Impractical from a layout perspective	No	No
Route Pipe to Avoid Areas of Occupation	Reduce potential dose to workers	Does not prevent breakout May introduce more bends than necessary	Yes	Yes
Area Radiation Monitoring/ Continuous Air Monitoring	Provides warning of the presence of a source and mitigates exposures by prompting evacuation	Does not prevent the event Monitors may not cover entire sample route	Yes – proven practice	Yes – As defense in depth
Fully Automatic Plant	Eliminates occupied areas, reducing worker exposure.	Not practical to remove all people from the facility	No – not proven for this level of complexity	No

Table 3.6-1. Initial Evaluation.

Control	Advantages	Disadvantages	Compliance with Top Level Principles	Further Consideration in Control Strategy
Use Coaxial Pipe	Provides additional physical barrier to initiating event	May introduce operational problems and increase occupational dose e.g. during recovery of a stuck sample carrier Cost	No – may increase radiation exposure	No
Routine Carrier Maintenance	Reduces pipe erosion	Difficult to quantify the performance of this control	Yes	Yes
High Reliability Carrier Lid	Reduces the potential for contamination spread in pipe and for sample release in the event of a breakout	Demonstration of integrity may be required	Yes	Yes
Condition Monitoring	Carrier check could reduce potential for carrier to come apart	Does not prevent carrier breakthrough	Yes	Yes
Improved Sample Bottle Integrity	Ensures confinement of the material in the bottle in the event of a drop	Would require drop tests to quantify the current bottle integrity versus an improved bottle	Yes	Yes
Reduce Sample Bottle Sampling Failures	Reduce the potential for contamination spread in carrier prior to a breakout event	Does not prevent the hazard of carrier breakthrough	Yes	Yes
Reduce Speed of the Sample Carrier	May reduce the frequency of breakout events	Reduction of frequency would be difficult to quantify Reduction in sample speed would increase occupational dose	No – increased radiation exposure	No

The following controls remained to be considered in formulation of the control strategy to be adopted:

- Improve piping material
- Strengthen pipe in key areas
- Increase the radius of pipe bends
- Use high integrity sample carrier (including high reliability lid)
- Sample transfer tracking
- Pipe run instrumentation
- Optimize pipe layout (reduce number of bends)
- Route pipe to avoid areas of occupation
- Area Radiation Monitoring/Continuous Air Monitoring
- Perform Routine Carrier Maintenance
- Perform Sample Carrier Condition Monitoring
- Improved Sample Bottle Integrity
- Reduced Sample Bottle Sampling Failures

3.6.3.2.2 Step 2 (Engineering Screen)

The preferred strategy was then developed through an engineering evaluation of the alternatives. This took account of the following considerations to ensure a comprehensive approach in the context of other hazards and the overall design.

- Introduction of secondary hazards

- Impact on safety features provided to protect against other hazards

- Impact of other hazards upon the control strategy

- Robustness to other fault conditions and environments (including seismic and other design basis events)

- Passive or active, and if active, automatic or administrative/procedural – order of preference

- Robustness of any administrative controls required

- Cost

- Operability

- Maintainability

- Ease of justification (e.g. consistency with proven technology)

The considerations are presented for the first five controls in Table 3.6-2, and for the remaining controls in Table 3.6-3 and Table 3.6-4.

Table 3.6-2. – First Group of Control Strategies

Criterion	Improved Piping Material	Strengthen Pipe in Key Areas	Increase Radius of Bends	High Integrity Sample Carrier	Sample Transfer Tracking
Introduction of Secondary Hazards	None	None	None	None	None
Impact on Safety Features Provided to Protect Against other Hazards	May increase the failure of the carrier inside the pipe.	None	None	None	None
Impact of other Hazards upon the Control Strategy Element	Material must be compatible with internal plant hazards (impact, fire, acid leaks)	None	None	None	None
Robustness to other Fault Conditions and Environments	Yes	Yes	Yes	Yes	Yes
Passive or Active	Passive	Passive	Passive	Passive	Active
Robustness of any Administrative Controls Required	Not Applicable to Control Strategy	Not Applicable to Control Strategy	Not Applicable to Control Strategy	May require routine maintenance	Requires maintenance Requires action on detection of sample fault
Cost	Increased purchase cost. Cost to evaluate new material and demonstrate compliance with the required integrity	Cost to demonstrate compliance with the required integrity	There may be a cost if it is required to quantify the improvement afforded by a radius increase	Cost to develop improved carrier and conduct drop tests, if needed	Cost for design and maintenance
Operability	System does not have experience with alternative pipe materials	Not demonstrated	Not demonstrated	Improvements to carrier, such as routine maintenance, have been implemented at THORP	Good operating practice; in use at Thorp

Table 3.6-2. – First Group of Control Strategies

Criterion	Improved Piping Material	Strengthen Pipe in Key Areas	Increase Radius of Bends	High Integrity Sample Carrier	Sample Transfer Tracking
Maintainability	System experience not available with alternative pipe materials	Should not introduce maintenance problems	Should not introduce maintenance problems	Improved maintenance of carriers demonstrated at THORP	Well-proven
Ease of Justification	Good engineering practice. Potential benefit perhaps not worth additional cost (would almost certainly involve development work)	Seems as if it should be good engineering practice but not proven	Good engineering practice	Could produce significant reduction in event frequency, if needed. Validation (by drop tests) would be needed if improvements went beyond BNFL experience	Proven practice

Table 3.6-3. Second Group of Control Strategies .

Criterion	Pipe Run Instrumentation	Optimize Pipe Layout (minimize bends)	Route Pipe to Avoid Occupied Areas	Use Area Radiation Monitors / CAMs
Introduction of Secondary Hazards	None	None	None	None
Impact on Safety Features Provided to Protect Against other Hazards	None	None	None	None
Impact of other Hazards upon the Control Strategy Element	None	Crane operation. Equipment movement	None	None
Robustness to other Fault Conditions and Environments	Yes	Yes	Yes	Yes
Passive or Active	Active	Passive	Passive	Active
Robustness of any Administrative Controls Required	Requires maintenance Requires controls to ensure sample system not used.	Not Applicable to Control Strategy	May require controls to prevent establishing new occupied areas in the vicinity of piping	Requires maintenance and calibration and response to alarms
Cost	Cost for design and maintenance	Minimal cost to evaluate and implement layout instructions	Minimal cost to evaluate and implement layout instructions	Radiation monitoring will be conducted as part of ongoing TWRS-P Programs
Operability	Good operating practice; in use at THORP	Good engineering practice	Good engineering practice	Good radiological protection practice
Maintainability	Well-proven	Should not introduce maintenance problems	Should not introduce maintenance problems	Should not introduce maintenance problems Increased burden if additional monitors installed
Ease of Justification	Proven practice	Good engineering practice	Good engineering practice	Good radiological protection practice

Table 3.6-4 Third Group of Control Strategies .

Criterion	Routine Carrier Maintenance	High Reliability Carrier Lid	Carrier Condition Monitoring	Improved Sample Bottle Integrity
Introduction of Secondary Hazards	None	None	None	None
Impact on Safety Features Provided to Protect Against other Hazards	None	None	None	None
Impact of other Hazards upon the Control Strategy Element	None	None	None	None
Robustness to other Fault Conditions and Environments	Yes	Yes	Yes	Yes
Passive or Active	Active	Passive	Active	Passive
Robustness of any Administrative Controls Required	Requires operating procedures	Provides for easy installation. Minimizes chance of misthreading	Requires maintenance and calibration	Requires quality control to ensure continued performance
Cost	Cost for time and materials	Cost for design/ development	Cost for development, design, and maintenance	Cost for redesign and testing of existing and improved bottles
Operability	Good operating practice; in use at THORP	Good operating practice; in use at THORP	System not demonstrated	Good operating practice; in use at THORP
Maintainability	Well proven	Should not introduce maintenance problem	System not demonstrated	Well proven
Ease of Justification	Proven practice	Good engineering practice	System not demonstrated	Proven practice

3.6.3.2.3 Control Strategy Selected

As has already been demonstrated, a mature control strategy exists that satisfies the requirement of this event (Sections 3.6.1.5 and 3.6.2.4).

The primary element that prevents breakout of a carrier to an occupied area is the pneumatic piping. Therefore, optimizing piping design to maximize its performance is the preferred strategy. Specifically, reducing the number of bends and strengthening the pipe in key areas will be adopted. Improving the pipe material and increasing the radius of bends will not be pursued since they are outside the experience base and there is no requirement to pursue these. The target is met.

The pipe routing will be selected to avoid areas of occupation whenever possible. Also, the carrier maintenance improvements recommended from the BNFL experience, such as replacement of seals, will also be implemented. Carrier condition monitoring will not be developed, however. Again, there is no driver. If BNFL implements and proves improvements on its Sellafield systems, consideration will be given to adopting them here, taking into account all factors (TWRS-P experience, cost, etc.).

In the event of carrier breakout, the elements that prevent release are the sample bottle and carrier. Ejection of the carrier from the piping without loss of the sample has significantly lower dose consequences than in the case where containment is lost. Although the facility worker would still receive an external dose upon carrier breakthrough, it is not significant. Dose from external exposure alone when based upon the maximum occupancy of eight hours is 0.08 rem. The frequency target of <0.1/y for the event is achieved by the escape frequency alone with a wide margin. Therefore, those elements of the control strategy that help to maintain containment of the sample carrier and have already been proven on BNFL's THORP system will be adopted.

Similarly, those aspects of the THORP system which have been implicitly claimed from the THORP data to establish the frequency for this event will also be included. These are the pipe run instrumentation and sample tracking system.

Worker evacuation in response to a local area radiation monitor/activity in air alarm or by managerial control when prompted by the carrier tracking system will further mitigate this event and is good practice. They are administrative controls that will be implemented but not claimed as an element of the control strategy for this event.

In summary, the Control Strategy is as tabulated below:

Table 3.6-5. Sample Carrier Breakout Event Control Strategy

Element	Note
• Optimize pneumatic piping integrity by good design and operational practice within experience base	Passive feature (Maintenance of felt seals requires administrative controls) This element is composed of a combination of strategies from Tables 3.6.2, 3.6.3, and 3.6.4, including strengthening pipe in key areas, optimizing pipe layout, routing pipe to minimize/avoid occupied areas, and performing routine carrier maintenance
• Use a robustly designed carrier, as used at THORP	Passive feature

Table 3.6-5. Sample Carrier Breakout Event Control Strategy

Element	Note
• Use a high integrity sample bottle, as is used at THORP	Passive feature
• Pipe run pressure instrumentation	Active feature
• Time of flight measurement and alarm aspects of the sample tracking system	Active feature

3.6.3.3 Structures, Systems, and Components that Implement the Control Strategy

The SSCs that implement the selected control strategy for the sample carrier breakout hazard are:

- Pneumatic Transfer Lines (important to safety)
- Sample Carrier (important to safety)
- Sample Bottle (important to safety)
- Pipe run pressure instrumentation (important to safety)
- Sample tracking system (important to safety)

3.6.4   Safety Standards and Requirements

3.6.4.1 Reliability Targets

The frequency target for the event is $<10^{-2}$/y, commensurate with the severity level, which is taken as SL-3. The frequency derived in Section 3.6.2.4 for HLW sample breakout of 5.1×10^{-3}/y therefore achieves the required reliability. It is nonetheless considered prudent to assign reliabilities to the control strategy elements to ensure the UK data used to derive this frequency is applicable, i.e. the designs are equally robust. Conservative values have also been taken for the probability of the carrier and sample bottle containment failing based on knowledge of equivalent UK systems.

The following reliability targets are therefore assigned to the important to the safety SSCs which comprise the control strategy:

Pneumatic transfer lines should not allow carrier breakout more frequently than 2 per 72,000 samples (2 per 432,000 flights).

Sample Carriers should achieve a probability of failure in the event of breakout of less than 0.1.

Sample bottles should achieve a probability of failure in the event of a breakout of less than 0.001.

Achievement of the above reliability targets is considered readily achievable based on experience from existing systems in the UK (Longfellow 1999) that reduce the event frequency significantly below the frequency target.

3.6.4.2   Performance Requirements

The performance requirement for this system is that it will reliably transfer samples without experiencing a carrier breakout. If a carrier breakout does occur, the performance requirements are that the sample will remain contained.

The fan used to operate the pneumatic transfer system must not be capable of pulling enough vacuum to collapse the pipe.

The pipe run pressure instrumentation must reveal damage to pipe (e.g., loss of vacuum) and inhibit carrier flight. This is to prevent transfer of samples into damaged piping, reducing the likelihood of a breakout.

The sample tracking and alarm system must reveal a reduction in felt thickness (as indicated by reduced carrier speed) before it proceeds far enough to cause pipe damage.

3.6.4.3   Administrative Measures

The administrative measures of this control strategy are:

Normal Operations

Normal operations will be conducted in accordance with approved operational safety requirements and in strict accordance with administrative and procedural control. Operators will be trained and assessed on the conduct of normal operations. Operational procedures, routine schedules and records will augment training.

Arrangements for the examination, inspection, maintenance and testing of all ITS equipment will be managed through a plant maintenance schedule (PMS). All maintenance activities will be carried out using appropriate maintenance instructions.

Specifically, improved carrier maintenance, such as instituted at BNFL THORP facility at the Sellafield Site, is included. This includes routine replacement of felt carrier seals.

Operator Response to Abnormal Conditions

Operators will be trained to identify, diagnose and respond to abnormal operating conditions. Plant information will be relayed to the operator in such a manner to aid the operator in performing this duty. Typically, any deviation of the process from its normal operating condition will generate an alarm appropriate to its importance, e.g., sample tracking alarm indicating a slowed or stuck sample carrier. This alarm will annunciate at the operator workstation or locally within the facility. Operational procedures will detail the:

- Actions the operator must perform to minimize the impact of the abnormality (e.g., local evacuation, and provision of local radiation shielding).

- The potential initiators.

- The follow up actions required, when plant conditions have been stabilized.

3.6.4.4 Administrative Standards

Operation of the TWRS facilities shall be conducted in accordance with proven practices from BNFL operations in the UK and the US. Arrangements will be placed to maintain and demonstrate compliance with all Safety Criteria detailed within the authorization basis.

Administrative arrangements will provide the framework for how facility operations will be conducted for all modes of operation, be that normal, maintenance or emergency preparedness.

The conduct of operation guidelines will be generated by the tailored application of appropriate sections of the following standards:

IAEA 50-C-0: Code on the Safety of Nuclear Power Plant Operations
DOE order 5480.19 "Conduct of Operations Requirements for DOE Facilities".
DOE order 4330.4B "Guidelines for the Conduct of Maintenance at DOE Nuclear Facilities".
"Appropriate Standards" from the Institute for Nuclear Power Operations.

This framework of conduct will be implemented through:

* Management and organizational structure.

* Documents, records and certification, including response to abnormal operating conditions, key compliance recording and archiving.

* Structured training programs for all personnel, tailored to their roles and responsibility.

* Emergency preparedness implemented by having an emergency response structure, training, exercises and procedures.

* Incident reporting arrangements.

* Safety documentation hierarchy, with appropriate flow down of information into operational documentation. All safety implications will be clearly identifiable within the operational procedures.

* Quality assurance.

* Arrangements for the examination, inspection, maintenance and testing of all ITS equipment.

* Labeling of ITS equipment clearly on the facility.

3.6.4.5 Design Standards

Specific design standards will be developed based on the specifications for sample carriers, and sample bottles in use at THORP. At present, Volume II of the *Safety Requirements Document*,
(BNFL Inc. 1998d) contains implementing standards for confinement design, including for piping, in Section 4.2.

The pneumatic transfer piping is constructed of unplasticized polyvinylchloride (uPVC). The BNFL

Pipeline Specification, Referenced "VE", identifies commercially available uPVC piping with specific dimensions. The BNFL piping specification has been used for this specific duty extensively for many years at BNFL's Sellafield Plants. The piping provides a resilient system, capable of withstanding a wide range of environmental conditions. The SRD incorporates this BNFL Pipeline Specification.

The design standard for the sample transfer system pneumatic piping will include distinctive marking so that it can be identified in occupied areas. In addition, the layout will require placement of the pneumatic piping so that it is not damaged during any subsequent maintenance work. For example, the piping should be placed so as to avoid the potential for people to climb on it or to rest ladders against it, etc.

The design standard will include requirements for optimizing the piping layout through occupied areas, including maximizing distance from operators, minimizing bends, and locating bends so as to avoid a breakout that is "aimed" at personnel.

3.6.4.6 Design Standards Not in the Safety Requirements Document

Design Standards not currently in the Safety Requirements Document are:

- Sample carriers
- Sample bottles
- Pneumatic piping marking and layout optimization
- Pneumatic system pressure instrumentation and alarms
- Sample tracking system and alarms
- Pneumatic system fan

3.6.5   Control Strategy Assessment

3.6.5.1 Performance Against Common Cause and Common Mode Effects

A seismic event is a possible initiator of carrier breakthrough independent of the frequency associated with other failure modes. It is necessary to ensure that this does not make a contribution to risk that could challenge achievement of the relevant target frequency for the event.

Design basis seismic events by definition have a frequency of 5×10^{-4}/y (DOE 1996 and BNFL Inc. 1998e). (This assessment will be valid for beyond design basis seismic events, which will have a lower frequency). This is below the target frequency for SL-3 events and so gives rise to no seismic qualification requirements or need for further consideration. Sub-design basis events may be of higher frequency. The effect of these still requires evaluation. **Open Issue.**

Aircraft Strike

The HAR derived a frequency for aircraft crash into the TWRS facility as 4.5×10^{-6}/y (BNFL Inc. 1998a).

This is well below the target frequency and need not be considered further.

Common Cause Event

A fire could initiate a sample carrier breakout and failure of the sample carrier and sample bottle. Fire alarms, however, would ensure that personnel do not remain in the vicinity.

3.6.5.2 Comparison with Top Level Principles

The preferred control strategy is evaluated below against a set of relevant top level radiological, nuclear and process safety standards and principles (DOE-RL 1998), as laid out below.

3.6.5.2.1 Defense in Depth (DOE/RL-96-0006)

Defense in depth is one of the general radiological and nuclear safety principles in DOE/RL-96-0006. SRD Volume II, Appendix B contains the BNFL *Implementing Standard for Defense in Depth.* This Implementing Standard governs application of the defense in depth principle on the TWRS-P project.

To satisfy the application of defense in depth, the Implementing Standard requires that the elements of the control strategy must ensure "…that no one level of protection is completely relied upon to ensure safe operation. This safety strategy provides multiple levels of protection to prevent or mitigate an unintended release of radioactive material to the environment."

DOE/RL-96-0006 formulates the defense in depth principle in terms of the following six sub-principles:

- Defense in depth
- Prevention
- Control
- Mitigation
- Automatic Systems
- Human Aspects

SRD Volume II, Appendix B contains the BNFL Implementing Standard for Defense in Depth. This implementing standard governs application of the defense in depth principle on the TWRS-P project and addresses each of the six sub-principles in DOE/RL-96-0006. The following paragraphs describe application of the Implementing Standard for Defense in Depth to the control strategy for sample carrier breakout.

1. Defense in Depth (DOE/RL-96-0006)

DOE/RL-96-0006, Section 4.1.1.1, requires the following:

"To compensate for potential human and mechanical failures, a defense-in-depth strategy should be applied to the facility commensurate with the hazards such that assured safety is vested in multiple, independent safety provisions, not one of which is to be relied upon excessively to protect the public, the workers or the environment. This strategy should be applied to the design and operation of the facility." (DOE/RL-96-0006, Section 4.1.1.1)

Section 3.0 of the BNFL Implementing Standard for Defense in Depth addresses this aspect of the defense in depth principle specifically. For SL-3 EVENTS, Section 3.0 of the *Implementing Standard for Defense in Depth* requires the following:

- At least one physical barrier to confine the radioactive material
- Consideration of two or more independent physical barriers to confine radioactive material
- A target frequency of $<1.0 \times 10^{-2}$/y for the SL-3 consequences

The control strategy includes three physical barriers against the release of radioactivity as a result of transporting samples: the sample bottle, the sample carrier that contains the sample bottle, and the pneumatic pipe through which the sample is transported. This exceeds the requirements of the Implementing Standard.

The analysis in Section 3.6.5.6 shows that the control strategy reduces the frequency of SL-3 level consequences from sample carrier breakout to 5.1×10^{-7} per year. This satisfies the target frequency in the Implementing Standard by a wide margin. Also, the frequency estimates indicate that the control strategy does not place excessive reliance on any single element to achieve this result.

The remaining five sub-principles of defense in depth are addressed below:

2. Prevention (DOE/RL-96-0006 4.1.1.2)

The primary means of preventing the accident is the provision of three layers of confinement, including the transfer lines, the sample carrier, and the sample bottle that together give an acceptably low frequency of carrier breakthrough and resultant loss of containment.

3. Control (DOE/RL-96-0006 4.1.1.3)

The pneumatic sample transfer system will be controlled during normal operations, anticipated operational occurrences, and maintenance so that facility and system variables remain within their operating ranges and the frequency of demands placed on structures, systems, and components important to safety is small.

4. Mitigation (DOE/RL-96-0006 4.1.1.4)

The containment, provided both by the sample bottle and the sample carrier, provides mitigation in the event of a carrier breakout and reduces the potential dose by reducing the frequency of loss of sample. Further, the facility is designed to retain the radioactive material and to protect the workplace and the environment in the event of a sample carrier breakthrough.

5. Automatic Systems (DOE/RL-96-0006 4.1.1.5)

Automatic systems (that would place and maintain the facility in a safe state and limit the potential spread of radioactive materials when operating conditions exceed predetermined set points) are not employed in the control strategy adopted.

6. Human Aspects (DOE/RL-96-0006 4.1.1.6)

The human aspects associated with pneumatic sample transfer follow proven examples and will be executed within the project procedures

Since the Severity Level for the sample carrier breakout hazard is SL-3, per Section 2.6.2 of the *Implementing Standard for Defense in Depth,* the control strategy need not be reviewed against the human factors engineering criteria in IEEE Std. 1023-1988 6.1.1, as tailored by the *Implementing Standard.*

3.6.5.2.2 Operating Experience and Safety Research (DOE/RL-96-006 4.1.2.4)

The adopted methods build on operating experience. The existing pneumatic sample transfer system at THORP has undergone significant testing and safety analysis work.

3.6.5.2.3 Proven Engineering Practices (DOE/RL-96-006 4.2.2.1)

The design is based on proven equipment and practices.

3.6.5.2.4 Common Mode/Common Cause Failure (DOE/RL-96-006 4.2.2.2)

A fire could be a common cause of failure of the sample transfer system. Analysis will continue as the design detail develops.

3.6.5.2.5 Safety System Designs and Qualification (DOE/RL-96-006 4.2.2.3)

The operating conditions for the SSCs are known and addressed in the design. Effects such as aging are well characterized for equipment of the type selected.

3.6.5.2.6 Radiation Protection Features (DOE/RL-96-006 4.2.3.2)

The pneumatic sample transfer system is specifically designed to protect workers from radiation exposure by virtue of distance and the transient nature of the sample carrier travel. The control strategy has been subjected to an as low as reasonably achievable (ALARA) design review which concluded that the selected strategy has no adverse ALARA impact.

3.6.5.2.7 Deactivation, Decontamination, and Decommissioning (DOE/RL-96-006 4.2.3.3)

The presence of the pneumatic sample transfer system will aid in plant decontamination and decommissioning. It does not in itself complicate Deactivation, Decontamination, and Decommissioning.

3.6.5.2.8 Emergency Preparedness – Support Facilities (DOE/RL-96-006 4.2.4.1)

The strategy has no foreseeable impact on the control room or emergency response center that may require to be manned after an event.

3.6.5.2.9 Inherent/Passive Safety Characteristics (DOE/RL-96-006 4.2.5)

The integrity of the sample transfer lines provides passive safety in preventing a carrier breakthrough. The sample carrier and sample bottle provide passive mitigation against an inhalation dose to the worker and public by preventing a loss of containment.

3.6.5.2.10 Human Error (DOE/RL-96-006 4.2.6.1)

The system is designed to the degree practical to mitigate the possibility of human error.

3.6.5.2.11 Instrumentation and Control Design (DOE/RL-96-006 4.2.6.2)

Instrumentation is provided to assist the operator with sample transfers and to control the sampling system and alert the operator to abnormal situations.

3.6.5.2.12 Safety Status (DOE/RL-96-006 4.2.6.3)

Not applicable.

3.6.5.2.13 Reliability (DOE/RL-96-006 4.2.7.1)

The SSCs which implement the control strategy achieve the reliability demands of this event.

3.6.5.2.14 Availability, Maintainability, and Inspectability (DOE/RL-96-006 4.2.7.2)

The equipment specified is well suited to, and has experience of being subjected to, well-characterized inspection, testing, and maintenance regimes.

3.6.5.2.15 Pre-Operational Testing (DOE/RL-96-006 4.2.8)

The control strategy is amenable to pre-operational testing of its elements, and experience of this exists for these elements.

3.6.5.3 Mitigated Consequences

If the sample bottle and carrier function as designed, the dose due to inhalation would be eliminated, so that only direct radiation exposure would occur. This would reduce the dose to the operator from 0.84 rem to about 0.08 rem.

3.6.5.4 Frequency of the Mitigated Event

The frequency of the mitigated consequences is 5.1×10^{-3}/y, as described in Section 3.6.2.4.

3.6.5.5 Consequences With Failure of the Control Strategy (including Mitigation)

If all of the preventive and mitigative measures fail, the unmitigated consequences are 0.84 rem to the facility operator, as described in Section 3.6.2.3.

3.6.5.6 Frequency of Control Strategy Failure

In order for the sample to lose containment, all the elements of the control strategy must fail, not only must the carrier break out from the pneumatic pipe (initiating event), but the sample carrier and the sample bottle must also both lose containment. There have been no instances where carriers have come apart due to falling or other impact events at THORP. (Prior problems were due to the carrier latching systems, which have been improved to prevent the carrier being open in the pipe). In addition, sample bottles have not spilled their contents during informal, random drop tests (Longfellow 1999). **Assuming** a failure probability of 0.1 for the carrier and 0.001 for the sample bottle results in a frequency of control strategy failure of:

(5.1 x 10^{-3} HLW sample breakouts per year) x (10^{-1} carrier failures/breakout) x (10^{-3} sample bottle failures/carrier failure) = 5.1 x 10^{-7} HLW sample releases per year.

The actual frequency is less than this, because the estimate does not take into account the fact that only a part of the pipe is located in occupied areas.

The table below summarizes the results of this analysis:

Summary of Results (Mitigated)[a]

Population	Dose (rem)	Severity Level	Frequency (y^{-1})
Facility Worker	0.08	SL-4	5.1 x 10^{-3}
Co-located Worker	<<2.0 x 10^{-4}	SL-4	5.1 x 10^{-3}
Public	<<2.9 x 10^{-7}	SL-4	5.1 x 10^{-3}

[a]All pathways

Summary of Results with Failure of Control Strategy[a]

Population	Dose (rem)	Severity Level	Frequency (y^{-1})
Facility Worker	0.84	SL-4 (SL-3 assumed)	5.1 x 10^{-7}
Co-located Worker	2.0 x 10^{-4}	SL-4	5.1 x 10^{-7}
Public	2.9 x 10^{-7}	SL-4	5.1 x 10^{-7}

[a]All pathways

3.6.6   Conclusions and Open Issues

3.6.6.1   Conclusions

The preferred control strategy, associated SSCs, and identified standards are capable of providing an acceptable level of protection against the potential hazard of HLW sample carrier breakout within the TWRS-P facility. The control strategy is summarized in Table 3.6-6.

3.6.6.2   Open Issues

Some open issues have been identified for further investigation and resolution as part of design development. These are:

1. Design Standards. Design standards for the automatic sampling system and pneumatic sample transfer system need to be developed for TWRS-P, taking into account the improvements made on the THORP systems. The standards should include distinctive marking for the pipe in occupied areas, adequate supports, and placement to protect it from future damage during maintenance in its vicinity.

2. <u>Pipe Routing</u>. The routing of the pneumatic piping will require control during design in order to minimize proximity to operators.

3. <u>Conventional Safety</u>. Conventional safety hazards associated with sample carrier breakout will need to be addressed as the design develops.

4. <u>Seismic Event.</u> The effects of below design basis seismic events require evaluation.

5. <u>Fire.</u> Risks associated with fire damage to the sample transfer system require evaluation.

In addition to the open issues listed above, various design and operational assumptions are highlighted in the report. Their continuous validity will be monitored through design development.

Table 3.6-6. Control Strategy Summary

Hazard Description:				Initiator:	
Carrier with HLW Sample Breaks out of the Pneumatic Transfer Pipe				Damage to the Pneumatic Transfer Pipe	
Selected Control Strategy	**Important to Safety SSCs**	**Safety Functions**	**Design Safety Features**	**Design Assumptions**	**Operational Assumptions**
Optimize pneumatic piping layout	Pneumatic Transfer Lines	To allow reliable transfer of sample carriers maintaining containment of carrier To withstand maximum vacuum fan can generate	Design should: Minimize the number of bends minimize routing through occupied areas	System equivalent to THORP PVC pneumatic piping	Piping will be subject to routine inspection/maintenance Loss of/reduced transfer performance will be investigated promptly
Provide for carrier to be compatible with the piping to reduce scoring of pipes	Sample Carrier/ sample carrier felt seals	To contain the sample bottle and travel reliably within the pneumatic piping	Design should: Minimize potential for carrier to damage pipework	Carriers will be designed for easy replacement of the felt seals	Seals will be replaced routinely to maintain travel performance so they do not score the inside of the pneumatic pipe
High-integrity Sample Bottle Including Improved Sample Needle	Sample Bottle and needle	To provide reliable containment of the sample	Robust bottle and stopper Durable needle – needle cannot be removed in stopper on withdrawal Bottle self-seals on needle removal	System equivalent to THORP Polyethylene bottle with self-sealing stopper	Use of strict QA and procedures to ensure integrity and correct preparation of bottles prior to sampling
Pipe run pressure instrumentation	Pressure indication and inhibition of carrier flight alarm/interlock	To prevent carrier flight into a damaged pipe	Design should: Detect damaged pipe (loss of vacuum during transfer cycle.) Prevent carrier flight on loss of normal vacuum Instrument should fail safe	System equivalent to THORP	Alarm/interlock will activate on loss of normal vacuum. (System only generates vacuum during sample transfer sequence.)
Sample Tracking System	Aspects that measure time of flight and alarm	To alert operators when carriers are slow-indicating a need for felt seal replacement-before the wear proceeds enough to cause pipe damage	Design should: Provide timing of sample carriers. Alarm if a carrier is slower then a pre-set value Instrument should fail safe	System equivalent to THORP	Response to a slow carrier alarm will include checking the felt seals.
Sample Tracking System to Warn of Non-arrivals	Not applicable Defense in Depth	To warn personnel and locate the site of the break			
Use area radiation monitors/continuous air monitors to warn of event	Not Applicable Defense in Depth	To warn personnel			

References

BNFL, 1995, *BNFL Pipeline Specification AVE*, pages 4 and 5, Issue A, December 20, 1995, BNFL Piping Functional Office.[a]

BNFL Inc., 1998a, *Hazard Analysis Report*, BNFL-5193-HAR-01, Rev 0, BNFL Inc., Richland, Washington

BNFL Inc., 1998b, *Technical Report*, BNFL-5193-TR-01, Rev. 0, BNFL Inc., Richland, Washington, January 23, 1998.

BNFL Inc., 1998c, *Initial Safety Analysis Report*. BNFL-5193-ISAR-01, Rev 0, BNFL, Inc., Richland, Washington, January 12, 1998.

BNFL Inc. 1998d, TWRS-P *Project Safety Requirements Document,* BNFL-5193-SRD-01, Rev. 2, BNFL Inc., Richland Washington, December 2, 1998.

DOE, 1996, *DOE Standard – Natural Phenomena Hazards Design Evaluation Criteria for Department of Energy Facilities*, DOE-STD-1020-94, Change Notice #1, U. S. Department of Energy, Washington, D.C.

DOE-RL, 1998, *Top-Level Radiological, Nuclear, and Process Safety Standards and Principles for TWRS Privatization Contractors*, DOE/RL-96-0006, Rev. 1, U.S. Department of Energy, Richland, Washington.

Elsden, 1999, *TWRS-P Contract No. DE-AC06-96RL13308-W375 - Material at Risk*, Memorandum No. 001673, BNFL Inc., Richland, Washington, February 10, 1999.[a]

Kummerer 1999, *Assignment of Severity Levels for High Level Waste Receipt Tank Rupture,* CALC-W375PT-NS-00001, Preliminary Calculation, BNFL Inc., Richland, Washington, February 1999. [a]

Longfellow, 1999, *Thorp Autosampling*, Memorandum to Rob Magraw, NL/1/AS/TWRS, BNFL Inc., Richland, Washington, February 12, 1999. [a]

Orme, 1998, *Waste Feed Delivery Technical Basis, Volume II, Waste Feed Delivery Flowsheet for Tank 241-AZ-101*, HNF-1939-Vol.II, Rev. 0a, R. M. Orme, Fluor Daniel Hanford Co, Richland, Washington, 1998.

Richards and others, 1997, *Hanford TWRS Plant Sampling Philosophy,* K0104-REP-005-PRC, V. Richards, D. Hughes and J. Richardson, BNFL Engineering Ltd., Manchester, United Kingdom, December 22, 1997.[b]

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[a] Copies of these references accompany this deliverable.
[b] For access to these documents, contact the Design Safety Features Point-of-Contact through the office of Safety and Regulatory Programs, TWRS-P, Richland, Washington.

Richardson, 1997, *RFD Delivered Sample Volumes*, Memorandum K0104_COR_140_MEC, BNFL Engineering Ltd, Manchester, United Kingdom, October 20, 1997.[a]

Sperinck, 1985, *The Selection of a Pipework Material for the Sellafield Cross-Site Pneumatic Sample Transfer System*, EDWP (85) P3, W. A. Sperinck.[a]

Woodruffe, 1999, *TWRS-P Contract No. DE-ACO6-96RL13308-W375 – Analysis of the Dose Rates from a Sample Container*, Memorandum No. 001397, BNFL Inc., Richland, Washington, January 18, 1999.[a]

Figure 3.6-1. Proposed Autosampling Scheme Identifying Pneumatic Transfer System and 'End Devices'
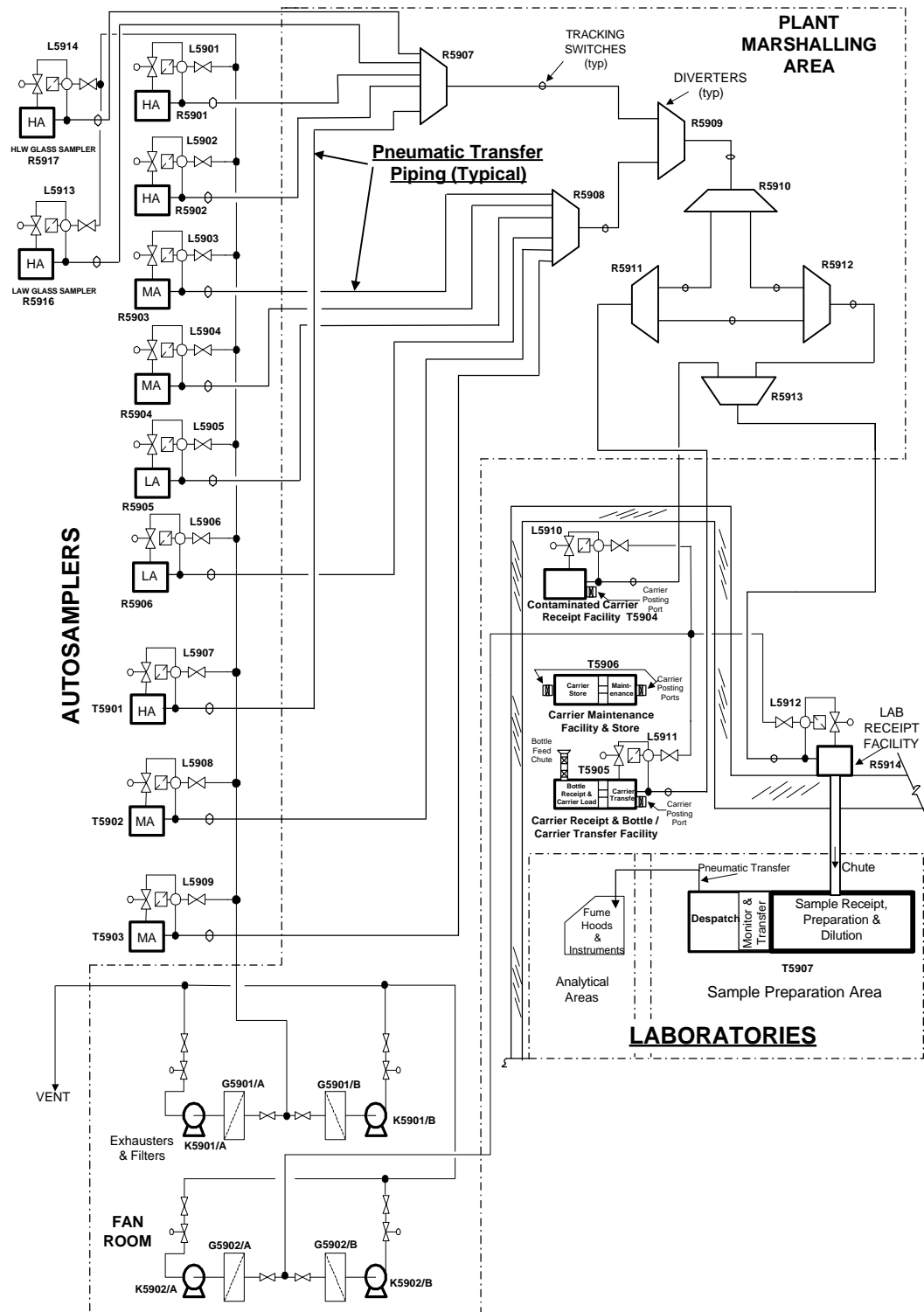
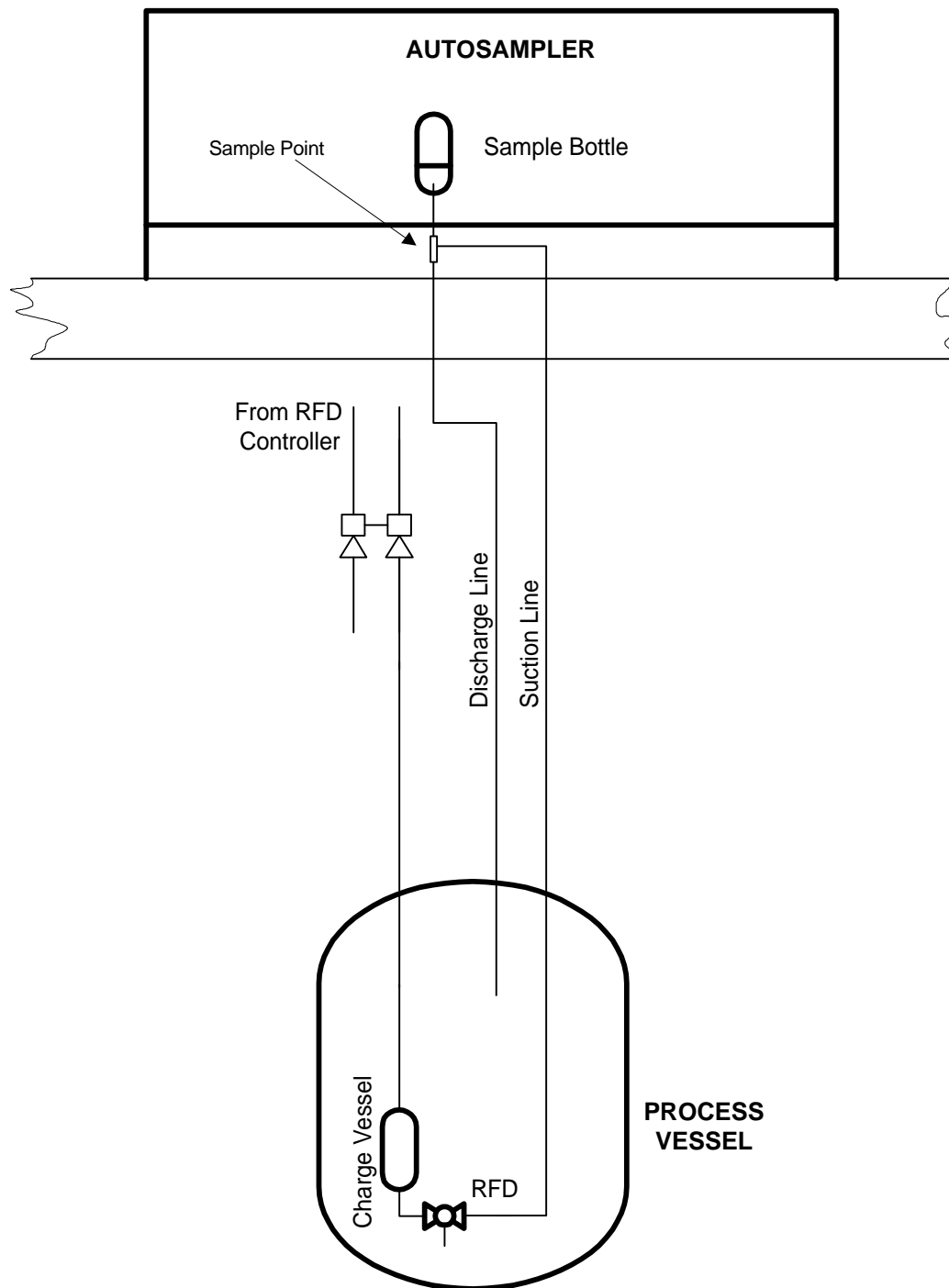**Figure 3.6-2. Typical RFD Fed Sample Point**

Figure 3.6-3. Proposed Arrangement of Automatic Sampler (Autosampler)

ISOMETRIC VIEW.